SUPERCRITICAL AND TRANSCRITICAL SHEAR FLOWS IN MICROGRAVITY: EXPERIMENTS AND DIRECT NUMERICAL SIMULATIONS

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ABSTRACT

The objective of this research, which began in April 2002, is to develop and experimentally validate a near-critical transcritical and supercritical fluid shear flow model independent of turbulence. We define a supercritical shear flow to be one in which all of the fluid particles remain above their critical temperature and pressure. We define a transcritical shear flow to be one in which at least some of the fluid particles undergo a transition between a subcritical and a supercritical temperature, between a subcritical and a supercritical pressure, or both. The reason it is necessary to validate the fluid model independent of turbulence is that turbulence introduces a large number of additional mechanisms the understanding of which is embryonic at best for near-critical transcritical and supercritical flows. Validating the fluid model without turbulence uncertainties therefore requires laminar flows. However, laminar flows that are not influenced by gravity are difficult to produce in normal gravity due to the large density gradients involved. Therefore, microgravity experiments are necessary.

The co-investigators have considerable experience modeling supercritical mixing and shear layers (JPL), and considerable experience in performing transcritical and supercritical droplet and jet experiments in normal gravity (AFRL/ERC). This experience will be applied to perform a microgravity experiment where the results can be directly compared with direct

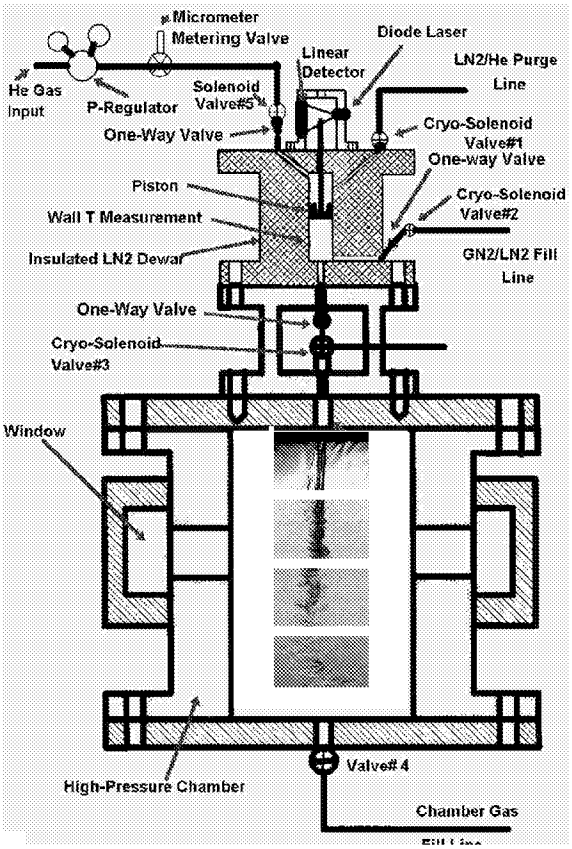

Figure 1. Preliminary Schematic of a Drop Tower Experiment; supercritical jet at 1 g..

numerical simulations. An entry into the related publications of the co-investigators can be found in refs. [1-3].

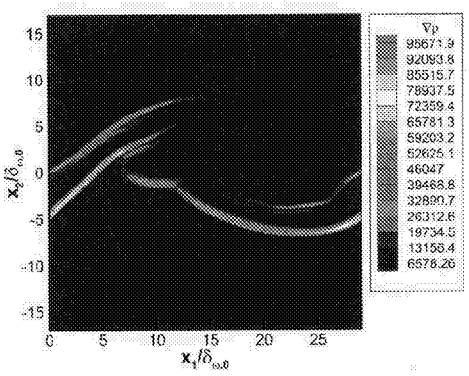

Figure 2. Density gradient magnitude computations in a laminar heptane/nitogen shear layer.

Experimental Approach

Liquid nitrogen (LN_2) initially below the critical temperature will be injected into room temperature gaseous nitrogen (GN_2) and GN_2/He mixtures at various subcritical to supercritical pressures. AFRL/ERC has considerable previous experience with these mixtures under normal gravity, and the substances are inherently safe. A conceptual design of the drop tower rig is illustrated in Fig. 1. Two separate chambers, one for LN_2, and the other for the ambient fluid, are connected through a one-way valve and a cryo-solenoid valve. The LN_2 chamber is an insulated dewar with several inlet and outlet passages as shown. Injection is achieved through pressurized He gas exerted on the upper side of a small piston inside the chamber. Injection initiation is controlled by the Cryo-solenoid-valve #3. The high pressure chamber will be designed to have optical access for flow visualization. The entire setup will be designed to withstand the total stresses caused by internal pressure and decelerating inertia forces. The volumes of the chambers are selected based on the test periods of less than 2.2 seconds and the range of flow rates desired to produce a range of Reynolds numbers, with minimal pressure rise during a test. Several ways to measure the instantaneous flow rates have been discussed, including the method shown in Fig. 1, where piston motion is detected by a diode laser and linear array optical array arrangement. The experimental procedure will be to complete chill down and establish the flow before the drop. Estimates confirm that there should be ample time for the flow to relax from 1 g to μg before the end of the drop.

Theoretical Approach

The theoretical approach includes real-gas equations of state, conservation equations that account for Soret and Dufour effects, and accurate transport properties. This model has already been validated with suspended-drop microgravity data. Preliminary simulations of a forced, laminar heptane/nitrogen mixing layer yielded encouraging results when compared to experimental observations of supercritical jets. An example of the simulation results is depicted in Fig. 2 showing the magnitude of the density gradient, which is pertinent to optical measurements: the finger-like features detected in the simulations qualitatively replicate some features observed experimentally [3]. Further studies will focus on using the same fluids in simulations and experiments, and performing simulations and observations at same conditions.

1. Harstad, K. and Bellan, J., Int. J. of Multiphase Flow, 26(10), 1675-1706, 2000.
2. Chehroudi, B., and Talley, D.G., 40th AIAA Aerospace Sciences Meeting and Exhibit, paper AIAA 2002-0342, Reno, NV, 14-17 January, 2002.
3. Chehroudi, B., Coy, E., and Talley, D.G., Physics of Fluids, 14(2), 850-861, 2002.